NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

April 1944 as Advance Restricted Report No. 4D29

WIND-TUNNEL PROCEDURE FOR DETERMINATION

OF CRITICAL STABILITY AND CONTROL

CHARACTERISTICS OF AIRPLANES

By Harry J. Goett, Roy P. Jackson, and Steven E. Belsley

Ames Aeronautical Laboratory Moffett Field, Calif.

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SUMMARY FRANCISCO STATE

This report outlines the flight conditions that are usually critical in determining the design of components of an airplane which affect its stability and control characteristics. The wind-tunnel tests necessary to determine the pertinent data for these conditions are indicated, and the methods of computation used to translate these data into characteristics which define the flying qualities of the airplane are illustrated.

INTRODUCTION

The development of flying-qualities specifications (references 1, 2, and 3) has established specific criteria with which the characteristics of an airplane normally will be compared. The problems posed in the preliminary design of an airplane is the determination of which of these criteria will influence the design of the various components of the airplane that affect the stability and control characteristics, and the magnitude of the effect. As an aid in this design problem, methods have been developed by which the data, obtained from wind-tunnel tests of powered models, can be translated into flying-qualities characteristics observable in flight tests (in the terms in which the flying-qualities specifications are written). Application of these methods to six different airplanes has indicated that the same requirements represent the critical conditions on all conventional airplanes, and that if these conditions are met,

it will follow that the remainder of the specifications will be satisfied. By permitting concentration on these few conditions, a considerable simplification of the design process results.

It is the purpose of this report to outline the critical conditions for each component of the airplane, to indicate the wind-tunnel tests necessary to determine the pertinent data, and to illustrate the methods of computation used to translate these data into characteristics which define the flying qualities of an airplane.

DISCUSSION

The flying-qualities requirements can be stated under three major headings:

- 1. Stability shall exist under specified conditions.
- 2. Control shall exist under specified conditions.
- 3. Control forces shall be kept within specified limits.

Each of these requirements is, to some extent, contradictory to the other two and, furthermore, airplanes now have been developed to such sizes and powers that the attainment of all three requirements is quite difficult. Hence, despite the fact that from the ultimate flying-qualities standpoint it is desirable to satisfy some of the requirements by as ample a margin as possible, the designer normally will find it expedient to base his original design on small margins, in order to minimize the difficulty of compromising conflicting requirements. If this is not done for one requirement, the attainment of the other two by normal means may be impossible.

To illustrate this point, the horizontal tail on a typical high-powered, single-engine airplane must be the smallest which will give the required stability in a rated-power climb, and the elevator must be the smallest which will give the required control in landing, in order to keep the balance requirements for low control forces in accelerated maneuvers within reasonable limits. With regard to wing dihedral, care must be taken not to exceed the amount required for the maintenance of lateral stability in the low-speed, high-power condition where the dihedral effect will be

minimum, or excessive dihedral effect will result at high speeds. The size of the rudder must be limited to the <u>smallest</u> that will give adequate control in order to keep the rudder-pedal forces within the required limits.

If it is assumed that the preliminary design has been completed on the above basis, it will be the function of the first wind-tunnel tests to obtain data from which any readjustments of the airplane components, necessary to secure satisfactory characteristics, can be determined. As conceived herein, the first series of wind-tunnel tests would be restricted to the critical conditions with regard to each characteristic. A series of tests sufficiently complete to form a basis for a more general flying-qualities prediction, or an analysis of secondary effects, would not be made until the changes shown to be necessary by the first series of tests had been incorporated in the model. An outline for such a preliminary series of tests as just discussed is given in tables I, II, and III for a singleengine airplane and in tables I, II, and IV for a twinengine airplane. An attempt has been made to make these tables self-explanatory when considered in the light of a flying-qualities specification (references 1, 2, and 3). Figures 1 to 16 present a typical set of results. The method of translating the wind-tunnel results into the terms of the flying-qualities specification is outlined on these figures.

The choice of critical conditions and the tables have been made after a detailed study of the characteristics of 3 typical single-engine airplanes and 3 twin-engine airplanes with right-hand rotating propellers. In each case it was found that if the 10 major points as outlined were satisfied, the other characteristics called for in the flying-qualities specifications would be met. It is believed that this conclusion will be similar for other conventional airplanes.

Each of the 10 items listed in the tables is directed toward 1 major variable in the airplane design. Thus, in the usual case

Horizontal tail size will be determined by item I.

Elevator size will be determined by item II.

Elevator balance will be determined by item III.

Minimum dihedral will be determined by item IV.

Maximum dihedral will be determined by item V.

Aileron size will be determined by item VI.

Aileron balance will be determined by item VII.

Vertical tail size will be determined by item VIII.

Rudder size will be determined by item IX.

Rudder balance will be determined by Item X.

Obviously there is a closer interrelation among the characteristics than the above listing implies, and important changes can be required after consideration of "secondary" variables. However, to a first approximation the variables listed will establish the airplane stability and control characteristics after the first basic arrangement of wing and fuselage is established. Changes in other features of the airplane components will normally be in the nature of refinements, rather than major changes.

The surface deflections given in the text are only representative values corresponding to the range of deflections needed in ascertaining the flying qualities of the airplanes upon which the study has been based. An optimum selection can be best determined from a cursory examination of the basic runs with control surfaces neutral, with due regard for the maximum deflections upon which the design is based. It will be noted that tail-off runs are called for in the tables only when they are necessary for the computation of the flying qualities. However, in order to provide data, which will aid in any necessary redesign, the addition of a tail-off run for other test conditions is considered desirable.

A typical set of data as obtained from the runs called for on the tables is shown in the figures, and the cross plots and computation methods necessary to reduce these data to the form of the flying-qualities characteristics are outlined. As in the table, these figures are intended to be in such detail as to require no further explanation. In the computation procedure certain simplifications and assumptions have been made, but it is believed that all factors which will bear an important influence on the final result have been included.

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APPENDIX

SYMBOLS

δ deflection of control surface

 $\Delta\alpha$ change in angle of attack at wing due to ground effect or change in angle of attack (over aileron station) due to roll

 $\Delta\varepsilon_1$ change in downwash at tail due to ground effect

 $\Delta\alpha t_1$ change in angle of attack of tail due to ground effect

 $\Delta\alpha_{\mbox{\scriptsize ta}}$ change in angle of attack of tail due to induced angle in accelerated flight

 $\mathtt{C}_{\mathtt{L}_{W}}$ lift coefficient of wing and fuselage (exclusive of tail)

it angle of incidence of tail

Ch hinge-moment coefficient

Ψ angle of yaw

β angle of sideslip

 T_c propeller thrust coefficient = $\frac{Thrust}{\rho V^2 D^2}$

 $c_{n_{oldsymbol{eta}}}$ yawing moment due to sideslip

Cla rolling moment due to sideslip

 ${
m Cl}_{
m p}$ rolling moment due to rolling

 ${\tt C_{l_a}}$ rolling moment due to alleron deflection

F stick force, pounds

V_i indicated airspeed

lH length from center of gravity to 25 percent M.A.C. of horizontal tail

n normal acceleration

- g acceleration due to gravity
- p rolling velocity, radians per second
- b wing span, feet

Subscripts

- e elevator
- r rudder
- a_I left aileron
- a_R right aileron
- t tail

NOTE: Stability axes have been used in the presentation of the data.

Positive deflection of control surface is in the direction which will produce a positive force (not necessarily a positive moment).

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Lateral Characteristics (Single and Twin-engine Airplanes)

TABLE II

It en	Purpose and requirement	Gritical condition	Run No.	Description Fig. of Run No.	S. Remarks
AI	To determine if the wing dihedral is great enough to provide at least neutral dihedral effect for the conditions of flight specified.	The critical condition will be in the approach with flaps down and with power on where power and flap effects combine to reduce the dihedral effect. (This condition will normally be worse with allerons free, but it can be checked to a very good first approximation with allerons fixed)	.	Yaw run at approach 5 attitude with flaps and gear down and 50 percent normal rated power. \$ 100 \text{vm - 300 to 300 } \$ 100 \text{vm - 200 to 300 } \$ 10	Army calls for stability at 1,2Vstall (propeller windmilling) with 50 percent rated power. Navy calls for stability in "the approach with considerable power". This condition will normally coincide with the condition outlined for the Army above.
	•			`	The angle of attack for these tests should be chosen on the basis of C _{Lmax} obtained in the wind tunnel (used in computing 1.2V _{stell}) but the power (T _o) should be set in accordance with the estimated speed under full scale conditions.
>	To determine if proper belance exists between dihedral effect and directional stability to avoid oscillatory divergence.	Critical condition will be the high speed (clean) condition where dihedral effect will be maximum and directional stability minimum (due to small power effects)	on .	Yaw run at high 6 speed attitude, flaps and gear up, propeller windmilling (or high-speed To) \$ = 00, \$ = 300 to 300	Some doubt exists as to whether or not this criterion expresses a true maximum limit for dihedral. It is believed that an airplene can have dihedral under this limit and yet have an undesirably large roll due to sideslip, and that the tolerable amount actually varies with the type of airplane. However no specific characteristic expressing such a criterion exists.
F	To determine if silerons are sufficiently effective to furnish minimum (Pb) max required.	Gritical condition will be at low speed (flaps up or down) where alleron effectiveness is usually lowest and reduction in $(\frac{p_0}{2V})$ due to yawing is greatest.	100 100 100 111 110	Polar with wind- milling propeller. Flaps and gear retracted \$a_1=0, \$a_m=0 \$a_1=3,4 up \$a_1=8ull Down, \$a_m=3/4 up \$a_1=8ull Down, \$a_m=8ull up Flaps and gear extended \$a_1=0, \$a_m=0 \$a_1=8ull Down, \$a_m=3/4 up \$a_1=8ull Down, \$a_m=8ull up \$a_1=8ull Down, \$a_m=8ull up	For a single-engine airplane runs ile, b, and c are needed for computations of necessary rudder balance. See Table No. III.
	To determine if allerons are closely enough belenced to furnish required (2V) max with low enough control forces.	Critical condition will be at highest speed at which requirement applies, normally .8V max . Required force and rate of roll varies with type of airplane.		Deta required will be 8 funcioned by runs 10s, b, end o, supplemented by two-dimensional hinge moment data.	For conventional-type allerous there are normally sufficient two-dimensional data at high Reynolds number which will form a reliable basis for stick-force computations.

Directional Characteristics (Single-engine Airplane)

TABLE III

Kamarks .		It should be noted that the condition for which the rudder is trimmed will bear an important influence on the rudder reversal characteristics. It is assumed that the incremental tab offects can be detimated and applied to tab-mero date.	It whould be noted that the condition for which the rudder is trimmed will beer as important influence on the radder reversal characteristics. It is assumed that the incremental tab offects can be estimated and applied to tab-sero data. For airplane being tested for compliance with Army opecifications only, the To and attitude requirements are less server and iny be changed to the following:	It should be noted that the condition for which the rudder is trimmed will beer as important influence on the rudder reversal characteristics. It is essumed that the incremental tab effect can date, and estimated and applied to tab-sero date. For airplane being tested for compliance with Army openifications only, the T _o and attitude requirements are less severe and may be changed to the following: Flaps up - T _o of power for lavel flight Plaps down - attitude of 1.2Vstall (propeller windmilling); T _o of 50 percent normal rated power. The above remark also applies to any airplane on which low-speed extreme power handling characteristics.	It should be noted that the condition for which the rudder is trimmed will beer an important influence on the rudder reversal characteristics. It is assumed that the incremental tab effects can be estimated and applied to tab-mer data. For airplane being tested for compliance with Army opecifications only, the T _c and attitude requirements are less sewere and may be changed to the following: Flaps up - T _c of power fur lawel flight Plaps down - attitude of laverall (propeller windmilling); T _c of 50 percent normal rated power. The above remark also applies to any airplane on which low-speed extreme power handling characteristics are considered of secondary importance. It should be noted that in computation of rudder required to hold steady sidensity, C _n due to alleron has been magnitoted (figs. 9, 10, 13, 14, and 16).	It should be noted that the condition for whole he rudder is trimmed will beer an important influence on the rudder reversal characteristics. It is assumed that the incremental tab effects con be estimated and applied to tab-mere data, shoremental tab effects con be estimated and applied to tab-mere data, dray opecifications only, the To and attitude requirements are less sewere and may be changed to the following: Flaps up - To of power fur lawel flight Plaps up - To of power fur lawel flight operand rated power. The above remark also applies to any airplane on which low-speed extreme power handling characteristics are considered of secondary importance. It should be noted that in computation of rudder required to hold steady sidelieved (figs. 9, 10, 13, 14, and 16). The data required to deformine actual powers allers your same estimed from hems il a, b, and s.	It should be noted that the condition for which the rudder is trimmed will bear an important influence on the radder reversal characteristics. It is assumed that the incremental tab effects can be estimated and applied to tab-mero data. For airplane being tested for compliance with Army opecifications only, the T ₀ and attitude requirements are less severe and ray be changed to the following: Flaps up - T ₀ of power fur lavel flight Plaps up - T ₀ of power fur lavel flight propeller windmilling); T ₀ of 50 percent normal rated power. The above remark also applies to any airplane on which low-speed extreme power handling characteristics are considered of secondary importance. It should be noted that in computation of rudder required to deformine actually C, due to allern has been ng-lected (figs. 9, 10, 13, 14, and 16). The data required to deformine actually data years alleren was exclinated to manifest of the figs. 9, 10, 13, 14, and 16). For airplanes boing tested for compliance with Army specifications only, analysis may be confined to condition (b), and attitude changed to large for power for level flight.	tr t	occupition med will med will med will when the tios. It nial tab d spplied d spplied d spplied d spplied d spplied or com- tions only, streme stoedy side- been neg- been neg- condi- tions only, condi- tions only, ocndi- ti
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To determine if sufficient	directional stability is present to avoid rudder force reversal or rudder force reduction at large angles of sideslip.					To determine if the rudder is large enough for nseessary control under all normal flight conditions.	o determin s large en seary com	o determine s large en seary conformal fili	To determine if the rudder is large enough for nseessary control under all normal flight conditions. To determine if the rudder has sufficient balance to keep the pedal forces within the required 180-pound limit.
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Directional Characteristics

TABLE IV

Gritical condition No. (a) Critical condition (b) The ortical condition (c) Fur run at spread with the stability will be at highest and the ortical condition will be at highest at a highest the there are at a highest the stability at a same of the stable of the stability at a same of the stable of the stability at a same of the stable of the stabl	Purpose and	pue		Run	Ulfectional Unaracteristics (Twin-engine Airplanes) Description Fig.	F. 0	
(a) Critical condition (b) The ortical condition (c) The virtual condition (d) The virtual condition (e) The range and for a calculating are set as a colled for an initial was a condition (e) The ortical condition will be remained by the critical condition will be a therefore taken a condition will be a therefore taken a condition will be a therefore the range a condition will be a the range a condition (a) The range a condition will be a condition will be a the range a condition (b) Each of the condition will be a condition will be a the range a condition (c) Hold at least 100 condition (d) The range a condition will be condition (e) Hold at least 100 condition (b) The range a condition will be condition. (c) Hold at least 100 condition will be condition. (d) The range a condition will be condition. (e) Hold at least 100 condition will be condition. (e) Hold at least 100 condition will be condition. (b) The range a condition will be condition. (c) Hold at least 100 condition will be condition. (d) The range a condition will be condition. (e) Hold at least 100 condition will be condition. (e) Hold at least 100 condition will be condition. (e) Hold at least 100 condition will be condition. (b) The range a condition will be condition. (c) Hold at least 100 condition will be condition. (d) Mar range a condition will be condition. (e) Hold at least 100 condition will be condition. (e) Hold at least 100 condition will be condition. (f) Hold at least 100 condition. (grandom: The condition will be condition. (d) Deta required is obtained from will be condition. (e) Bear a condition will be condition. (f) Bear a condition will be condition. (h) Hold at least 100 condition will be condition. (e) Hold at least 100 condition will be condition. (f) Hold at least 100 con	requirement	ont.	Critical condition	Š			Remarks
ta a high-thrust 12b 12b 12b 12c 12c 12c 12c 12c	To determine if sufficient directional stability is present	e if direc- llity	(a) Critical condition will be at highest anglesof right sideslip attainable when the			2	(a) Army calls for rudder-free directional stability at 1.2V _{stall} (propeller wind-milling) with 50 percent rated power and tab set for trim at zero sideslip. C _{h.} for tab
(b) The orition of the corresponding to articles of condition will be condition as with the ruded free and the condition in direction to bring wing with dead engine of the after cake. Critical condition will another the ruder free and the condition will condition will condition. Critical condition will condition will condition will condition. Critical condition will condition will condition will condition. Critical condition will condition will condition. (b) Kold at least 100 percent of the stalling condition. (c) Kold at least 100 percent of the stalling condition. (b) Kold at least 100 percent of the stalling condition. (c) May range = -20 to 100 condition. (d) May range = -20 to 100 condition. (e) Kold at least 100 percent of the stalling condition. (e) May range = -20 to 100 condition. (b) May range = -20 to 100 condition. (c) May range = -20 to 100 condition. (d) May range = -20 to 100 condition. (e) May range = -20 to 100 condition. (e) May range = -20 to 100 condition. (f) May range = -20 to 100 condition. (h) May range + fo20 condition. (h) May	(a) to avoid rudder pedal force reversels or	d 1 force r	propeller is operating at a high-thrust coefficient.	126 126	Yew renge = 0 to -300 \$r = 00 \$r = 100 \$r = 200		rean be estimated. Navy calls for no reduction of rudder pedal force as the angle of sideslip is increased,
off. Signification of the capture o	reduction at large angles of sideslip.	t large ideslip.	(b) The oritical condition will be represented by the	P21	6' = 250 (b) Yew run at attitude corresponding to 1.2V stall, flaps at take-off setting,		with take-off power and neutral trim tab. As the Navy does not give a definite minimum speed, l.ul $V_{\rm stall}$ (propeller windmilling) is assumed to be the lowest speed at which
Right engine operating the Army. \[\psi \) \text{This r} \\ \text{The Derivation will be power} \\ \text{This roll condition will be power} \\ Thi	(b) To permit the airplane to be balanced directionally in a steady flight, with rudder free and assummetric	ut the be rection- ady h rudder	salure of one engine shortly after take- off.	- 4	genr downake-or power on one engine, other engine, propeller windmilling. Meke runs with the rudder free and the ailerons set with full deflection in direction to bring wing with dead engine up.		this requirement need be met. Runs in right sideslip are called for since normally this will represent a more extreme condition than left sideslip.
Critical condition will be after single-engine falure where the rudder control should be power- ful enough to (a) hold zero sideslip at all speeds down to 120 per- speeds down to 120 per- speed down to 120 per- cont of the stalling speed down to 120 per- speed down to 120 per- condition. (b) Hold at least 10° of sideslip at 120 per- cent of the stalling speed in the take-off (b) Hold at least 10° of sideslip at 120 per- cent of the stalling speed in the take-off (c) Hold at least 10° of sideslip at 120 per- cent of the stalling speed in the take-off (a) Data required is obtained from shove.	power by banking to a moderate angle.	nking to		13a 13b	operating 30° operating 30°	. 14	(b) This requirement is not called for by the Army. Mavy specifications require engle of bank to be limited to 15°, 25°, or 35° depending on type of airplane.
(b) Hold at least 10° (1.2V _{gtall}) flaps in take-off position, of sideally at 120 per- ognition. left engine, propeller windmilling. speed in the take-off 15a (1.2V _{gtall}) flaps in take-off position. left engine, propeller windmilling. Yew range + 5 to -25° 15b (1.2V _{gtall}) flaps in take-off position. Incomplete of the stalling of the stalling of the take-off position. Incomplete of the	To determine if the rudder is capable of main-taining the required control under all conditions of steady flight.	is if is main-roll roll condi-	Gritical condition will be after single-engine failure where the rudder control should be power- ful enough to (a) hold zero sideslip at all speeds down to 120 per- cent of the stalling speed in the olean condition.	148 146 146	ting to	18	(a) This requirement applies only to Navy sirplenes.
Critical condition will (a) Data required is obtained from 15 be in the flight condi- tion (a) and (b) listed (b) Data required is obtained from 16 above.			or (b) Hold at least 10° of sideslip at 120 per- cent of the stalling speed in the take-off condition.	15m 15b 15c	flaps in take-off attitude flaps in take-off position, Take-off power on right engine; propeller windmilling. aw range + 5 to -25° br = 0° cr = 10° dr = -20° dr = -25°	91	(b) This requirement applies only for Army airplanes.
	To determine if the rudder has enough balance to keep the rudder pedal forces within the 180-pound limit.	e if the enough keep pedal in the imit.	Critical condition will be in the flight condi- tion (e) and (b) listed above.			5 B 5	(a) Most severe requirement applied by the Mary. (with respect to rudder pedal forces) (b) Requirement (b) is usually less severe than (a) but is the most severe applied by the Army.

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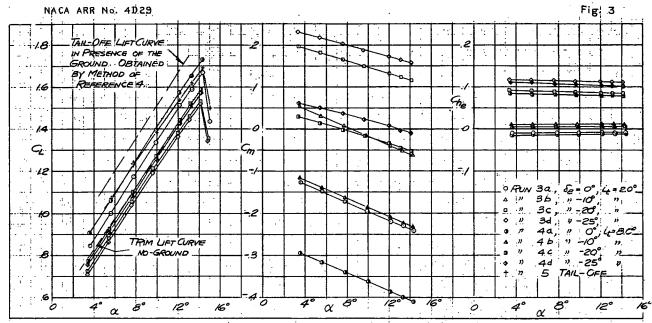
Fig. 1

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9	TAB C _{he} With tab Set for trim At la Vatall	16	
ଡ	Che FOR (3) AT 14 VERRIL (C. = 92) FROM CROSS RIOT	FOR FOR STEURE	
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©	FROM CROSSFILDT RES	1 178 1.5° -0.70 1 46 6 -0.30 1 126 0° -0.030 1 13 -4° -0.030 1 13 -4° -0.030 1 14 -4° -0.030 1 14 -4° -0.030 1 14 -4° -0.030 1 15 -4° -0.030 1 16 -4° -0.030 1 17 -4° -0.030	COMPUTATION
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0	G	4 6 8 6 4 4 5 E E	B

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AABLE.			\$		7.88		/ &		HIRPLANE STEADY FLIGHT CHARACTERISTICS
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COMPUTATION) (8)	2	1	8 8		Q
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D)				:: :	141 <u>,</u> .				

(A) MODEL CHARACTERISTICS DETERMINED FROM MINDTUNNEL Q (C) MODEL CHARACTERISTICS CROSSINGTIED -02 -0/Cheo C.9. AT 26-PERCENT WAC **60** 18 a Þ ٥. 0 4 Se = -10° Se = 5. و. و C. Ó O RUN ZO 75575 D RUN ZC ú o CONFIDENTIAL 9000 Ò

FIGURE 2.-VARIATION OF FLEVATOR ANGLE AND STICK FORCE WITH SOFED. STEADY FLIGHT WITH FLADS AND GEAR DOWN, 30 DERCENT NORMAL RITED DOWER.



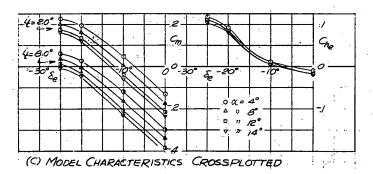
(A) MODEL CHARACTERISTICS DETERMINED, FROM WIND TUNNEL TESTS - C.g. AT 16-PERCENT MAC

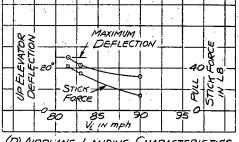
00	3	●	③ :	6	0	®	9	00	<i>:</i> ② .	(B) (B) (G) (G)	0
			774	B NEUTR	94					TAB. G. TO TRIM (9)	90
G, angle of attack of Reference line C., in Presence of Ground Corresponding TO G of O from Partia	E, DOWNWASH ANGLE 12. PRESENCE OF GROUND CORRESPONDING TO CW. OF © AND (OF O. OBTAIN ED FROM REF. 4.	THE OFF OF WITH MY GROWNING TO G., OF B.	G, DOWNNASH ANGLE WITH NO SROUND GFEELT COR- RESPONDING TO GW, OF AND K OR GR GO BERM.	∆€, INCREMENT OF DOWN WASH ANGLE AT TAIL DUE TO GROUND EFFECT FOWALS € OF ® MINUS © OF ®.	AG DUE TO GROUND EFFEC EQUALS & MINUS & AS OBTAINED FROM REF.4	LOGE, THE TOTAL CHANGE IN TAIL ANGLE OF ATTACK FEFECT GOUND BFFECT GOUND AG OF (O)	& FOR C, O, WITH 7911 MCIOENCE INGREASED BY INCREMENT EQUAL TO DOL, IOF ® AND WITH ANGLE OF ATTACK EQUAL TO G O O O O O O	C CORRESPONDING TO CORVE OF RART (A). KFOR C OF (D). WING. LOADING - 23 LB / 59, FT.	Che CORRESPONDING TO CA OF Q. DCL, OF Q., AND Se OF Q. FROM PART (C).	Ge FOR Cm = C, 100 SROUND, AT (4 King), FROM BAPTCH, (2, -5, 0) ROOM BAPTCH, (2, -5, 0) FROM BAPTCH, (2, -5, 0) FROM BAPTCH, (2, -5, 0) FROM BAPTCH, (2, 0) TAB Ge EQUALS TAB Ge EQUALS Che OF GE	STICK FORCE . F./99 = 83
//° 1.59	3. 3°	/2.9°	11.2°	-7.9°	-/.9°	6.0	-25*	1.48 814 mph	.105	-8.0° .005-005-100	AI.4 PULL

THE ABOVE COMPUTATIONS ARE FOR THE THREE POINT ATTITUDE. COMPUTATIONS FOR LANDING AT GREATER SPEEDS ARE MADE BY INTERPOLATING BETWEEN THE L. LIMITS OF PART (A).

THE RESULTS OF REFERENCE 5 INDICATE A SMALLER INCREASE IN C., AT A CONSTANT ATTITUDE DUE TO GROUND EFFECT, THAN THAT COMPUTED BY REFERENCE 4. REFERENCE 5 ALSO INDICATES A RITCHING MOMENT INCREMENT ON THE WING, DUE TO GROUND EFFECT THAT TENDS TO STALL THE AIRPLANE. THE COMPUTATIONS ABOVE DO NOT ALLOW FOR THE GROUND EFFECTS NOTED IN REFERENCE 5. THIS PROCEDURE RESULTS IN A CONSERVATIVE ESTIMATE OF S. AND STICK FORCE TO LAND (WITH RESPECT TO REF. 5).

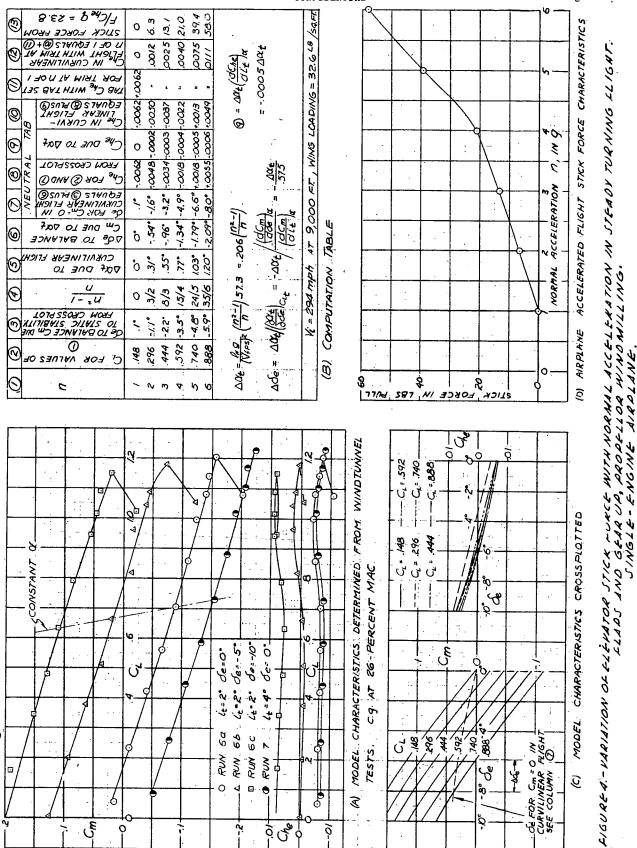
(B) COMPUTATION TABLE.





(D) AIRPLANE LANDING CHARACTERISTICS

FIGURE 3.-VARIATION OF ELEVATOR ANGLE AND STICK FORCE IN LANDING.
FLAPS AND GEAR DOWN, PROPELLOR WINDMILLING.
SINGLE-ENGINE AIRPLANE.



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SINGLE-ENGINE AIR DLANE. FLADS AND

AIGUREG.-LATERAL-STABILITY CHARACTERISTICS AT 4164.
SPEED, FLADS AND GEAR UP, RATED DOWER.

GEAR DOWN, SO PERCENT NORMAL RATED DOWER FIBURES .- DIMEDRAL CHARACTERISTICS AT LOW SOFFO. CONFIDENTIAL

DEFLECTION,

	0	TOTAL AILERON DEFLECTIO	30°	40°	30°	400	M REF 6) RMANCE		
	(9)	(Pb) RUDDER- LOCKED. @ש	660	811	820:		PEED (FRO) 116H PERFC	-	
	9	(Pb) max (PeV) max REDUCTION FRETOR— OUB TO SIDESLIP	/6.	16.	.80	.80	$C_{2\rho} = -0.47\pi$ High Speed and -0.43 at low speed (FROM REF 6). Believed to be representative of Modern High Performance Arranges. (Assumes a Rigid Wing)		
	Ø	CONDITION ALLERON MOMENT (PD) ($\frac{PD}{EV}$) $\frac{PD}{EV}$) ALLERONS EQUALS FROME TO ZERO SIDESLIP FROME FOR $\frac{PD}{PR}$ $\frac{PD}{$	60/	06/	.260	9//	-0.4747 HIGH SPEED AND -0.43 AT LOI FUED TO BE REPRESENTATIVE OF MODER AIRPLANES. (ASSUMES A RIGID WING)	(B) COMPUTATION TABLE, FLARS-UP	-
•	9	ROLLING MOMENT OUE TO AILERONS FROM	.05/	190	.042	090	THIGH SP BE REPR VES. (AS	N TABLE	-
	0	AILERON THROW	**	FULL	4%	FULL	= -0.474 EVED TO AIRPLA	PUTATIO	-
	0	CONDITION	HIGH-SPEED V:=0.8 Vmx	# 266 mph CL= 0.18 d = 0.2°	LOW-SPEED 1.2 Vsm.11	C _{L=} 0.86 α= 10.4°	2. BELL	(B) (Q)	Ĺ
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25			9			.	:		
7m2	الم ا		1) FLAPS UP		9		9 .		
S. S	0	4 8	1/6	F*;	9	اري	FULL	1 3 9	
	9				79		Cax a	3%	
A. FULL DOWN; Sax = FULL UP] (Jane Jane		11	* MEUTRA	8	FULL DOWN; Sar = FULL UP	9	K
a a		VmoQ	0 = 0	9	X	8	מור ב	' A NMOX	
	V a 41	Sa_ = 34 DOWN; Sag= 34	ر م	, —	601 = 60R = NEUTRAL	84	ا وق	E. = 34 DOWN : 60 = 94 UP	٠
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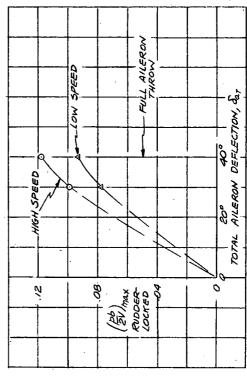
O. RUN 100, &= 0°, &= 0° A RUN 100, " 15°, " -15° B RUN 100, " 20°, " -20°

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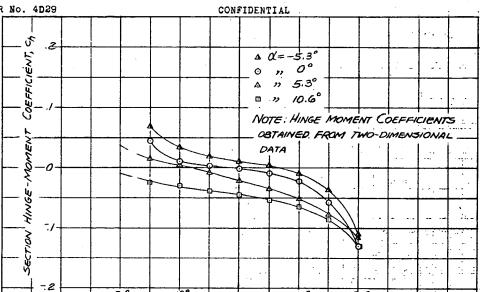
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(C) AIRPLANE ROLLING CHARACTERISTICS WITH FLAFS UP (POS/2V US ALLERON DEFLECTION).

FIGURE 7. - ALLERON CONTROL CHARACTERISTICS FLAPS AND GEAR UP. SINGLE-ENGINE AIRDEANE (A) MODEL CHAKACTERISTICS DETERMINED FROM WIND TUNNEL TESTS



AILERON DEFLECTION, Sa

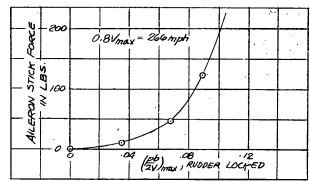
(A) HINGE MOMENT CHARACTERISTICS DETERMINED FROM WIND TUNNEL TESTS

0	2	3	@	⑤	6	3 .	0	9	0	0	-@
AILERON POSITION	LEFT AILERON DEFLECTION SOL	RIGHT ALLERON DEFLECTION OUR	(<u>PV</u>)max, FROM F16.7	NOVED ANGLE DUE TO ROLLING DA= 40.x @	4-0x ATTACK	RIGHT OVER EACH GR= A+CR A+CR A+CR A+CR	Cha FOR Ga, AND Of FROM (A) ABOVE	Gar FOR Gar AND GR FROMA) ABONE	SUMMATION Cha	STICK PORCE	AILERON CONTROL FORCE IN LAS F = @x f x @
0	0	0	0	0	0	0	-002	7002	0	12.3	0
1/4 THROW	5°	-5°	.035	/4°	-/4°	1.40	-005	0	.005		//
1/2 THROW	100	-100	.068	2.7°	-2.7°	2.7°	-015	.006	7021		47
3/4 THROW	/5°	-/5°	.089	3.6	-36°	36°	-044	.021	-065	-	123
FULL THROW	200	-20°	118	4.7°	-4.7°	4.7°	-/18	.041	7/59		354

 $\Delta \alpha = 40.4 \frac{Pb}{2V}_{max} = l_1 + l_2 \times \frac{Pb}{2V}_{max} \times 57.3$ WHERE l_1 AND l_2 ARE DISTANCES FROM PLANE OF SYMMETRY TO INBOARD AND OUTBOARD ENDS OF THE AILERON. 2 d = 0.2 AT 0.8 Vmax = 266mph ; q = 18148/sqfT

(B) COMPUTATION TABLE

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AILERON STICK FORCE CHARACTERISTICS IN STEADY ROLLS.

(C) AIRPLANE STEADY SIDESLIP CHARACTERISTICS.

	•							COI	VFIDENTIAL .
9	17 N 1-0KCE 1-0HT	i. I	34 K	B R	426	704	32.5 18 Karn		CUBDER PEDAL FORCE
9	-47 · b	26.6	"	"	"		1 11		
(b)	Chr FOR	.030	070	0/0.	- 050	- 055	LB /SQ.FT., WING LOADING	YON TABLE	Sipestip, A
<u></u>	-1/2 LOK C" = 0 EDNALS B FOR C" = 0	7.82-	-70.5.7	6.7°R	17.2°R	25.0'R	31.5 18 /50	COMPUTATION	S1.E
0	EGUALS ZERO		3 0	-6.7°	-17.2°	-250	6	(8) Cc	THE
0	HUDDER ANGLE	-25° R	-15° R	ů	7,2,7	25.7	1 = 111 mph.		STEEL BICHLES ON OF E
			8	O S C S C S C S C S C S C S C S C S C S	124			, , , , , , , , , , , , , , , , , , ,	
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FROURE 9.-VARIATION OF AUDDER ANGLE AND DEDAL LORCE WITH SIDESLID AT LOW SDEAD. FLADS AND GEAR UP, NORMAL RATED DOWER. SINGLE-ENGINE AIRDIANE.

(A) MODEL CHARACTERISTICS DETERMINED FROM WINDTWNNEL TESTS.

	NACA ARR No.	4D	29	,		·····
©	PEDAL PORCE	60	704	789	785	18/89.57
9	PEDAL FORCE	26.6	77	11	11	DING = 32.648
Ð	@ and @	.036	080-	- 6//-	-,/30	- , WING LOADING -
©	-1/2 12018 (P=0 EGUALS B 1=018 (P=0	2016	J.6.4°P1	18.4°R	30.9%	16.848 /SaFT
0	EGUALS ZERO	- 9.70	-16.40	-18.40	-20.9°	=81mph,9=1
0	RVODER ANGLE	0	7,5/	7,02	7,52	1/2 = 81

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(C) AIRPRANE STEADY SIDESLID CHARACTERISTICS (B) COMPUTATION TABLE 2º ø 0 Ø 4 ů. 0 8 E 8 3 Ó (A) MOREL CHARACTERISTICS DETERMINED FROM WIND-TUNNEL TESTS 1: . .<u>.</u>. 52,

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FIGURE 10.-VARIATION OF AUDUSA AND DEDAL FORCE WITH SIDE-SLID IN WAVE-OFF.
FLAPS AND GEAR DOWN, TAKE-OFF DOWER.
SINGLE-FNGINE AIRDLANE.

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NACA ARR NO		CON	FIDEN	TIAL											
17/2/ ₁₋₁ / 1/2 /	1	10 1	4.4° R	28°R	1.2° F	16 LB /50F)						d'4	Nug.	 20 37	3NY
SO 3 NA	DAY DAY	-, 325	/50	-,096	-040	W6 = 32.		S S		87 1 134 8	11 13001	Y_	3		912
N NAC FORCE O	PED PED	17 8	38R	121.8	1218	WING LOADING		8	3	``) 1#3)		
* CHE		26.6	"	"	~	16.8-18 150FT ,	E			FORKE	Y /		3	3	
B 307	10 W	+040	.222	172.	.272		١.					ANGLE /	١	ar BANK	व
0=4780= 6 97400 8 97400	3 >	9.0°P	2,61	7,50	7,62	81 mph, 9=	COMPUTATION							ANGLE	
MIS ZEBO	St.	-9.0	├		2.9°	= 3/	Com			00	2 14	א צופ	5		
DOER ANGLE	1 7	Ô	-15° R	-20°R	-25°P		(8)		<i>a</i>	7914				·	

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WIND-TUNNEL
FROM
DETERMINED
CHARACTERISTICS
(A) MODEL

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			44	- · - ·		ů_	FROM FIGILS,	1,50	\$ °				
			9	1		\$ - \$	<u> </u>	14a, Sp=	, , , , , , , , , , , , , , , , , , ,				
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						\$ —	9 8		\ = \				
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(C) AIRPLANE STEADY SIDESLIP CHARACTERISTICS FIGURE II.-RUDOER ANGLE AND DEDAL FORCE NECESSARY TO HOLD WINGS LEVEL IN WAVE-OFF. FLADS AND GEAR DOWN, TAKE-OFF DOWER. SINGLE-FNGINE AIRDLANE.

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	NACA ARE	N	o. 4 D2 9
Ø	Cho Ch DUE TO Ch TO BE FROM ROLLING OVERCOME FROM REF. EQUALS BY RUDDER FROM COMPAND BY RUDDER FROM COMPAND CO	6010-	ENT - AILERON
9	C, DUE TO ROLLING FQUALS Ø×Ø	-047 -0059	ING MOM. M RIGHT
3	Cip FROM PEFF	-047	XAN. XIMU
Ø	FROM FRUMES WAS A COURT S	./23	TABLE - YA DUE TO MAXIM
0	Sport REF.	E#'-	77 / 200
0	Grokful Grokful Gp pb/24 G_{p} Gp Chokful Grow Rolling OVERCOME $\frac{\pi}{5}$ SEE Fig. 7 Ref. $-0/3$ Ref. $60 \times 3 = 0+3$ Ref. $0 \times 3 = 0+3$	0050	COMPUTATION TABLE - YAWING MOMENT COEFFICIENT DUE TO MAXIMUM RIGHT AILERON
0	C, FOR FULL RIGHT AILERD SEE FIG. 7 $\alpha = 6$.053	(B) CO COE

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V TABLE - YAWING MOMENT DUE TO MAXIMUM RIGHT AILERON DEFLECTION. COMPUTATION TABLE \mathscr{B}

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OF PART (A)	°O II
 MODEL CHARACTERISTICS OF PART (A) C	PLOTTED AT W = 0.
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(HOKCE HOKCE HEDYT	26.6	32.6 18
©	C _n TO BE PRO- O' CORRESPOND- C _n CORRESPOND- 144 COUCED BY RUD- ING TO O. FROM ING TO O. FROM OC CROSS PLOT (C) CROSS PLOT (C) 144 COF (B) ABOVE. ABOVE.	.335	(=81 mph q=16.8 LB /sa.FT., WING LOADING=32.6 LB /sa.FT
0	Gr CORRES POND- Chr. CORRES POND- ING TO Q. FROM ING TO Q. FROI CROSS PLOT (C) CROSS PLOT (C) ABOVE.	-23.5° R	6.8 LB /SQ. FT.,
0	C, TO BE PRO- DUCED BY RUD- DER. FROM () OF (B) ABOVE.	60/0	1=6 4dm 18=1

FORCE ON AIRPLANE TO HOLD ZERO COMPUTATION TABLE - RUDDER ANGLE AND SIDESLIP WITH MAXIMUM RIGHT AILERON PEDAL Q

FIGURÈ 12. - RUDDER ANGLE AND DEDAL FORCE NECESSARY TO HOLD ZERO SIDESLID IN WAVE-OFF. FLADS AND GEAR DOWN, TAKE-OFF DOWER. SINGLE-ENGINE AIRDLANE.

(A) MODEL CHARACTERISTICS DETEMINED FROM WIND-

TUNNEL TESTS.

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Fig. 12

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FIGURE TO. -VATIATION OF AUDDER ANGLE AND DEDAL LORGE WITH SIDESLID AT ABPROACH SPEED. FLAPS AND GEAR DOWN, TAKE-OFF DOWER. THIN-FNGINE, THIN-TAIL AIRDLANE.

@	T, COEFFICIENT BANK, CL = W CL = W CL = W	:5,1° RIGHT
8	AIRPLANE LIFT COEFFICIEN $C_L = \frac{W}{4S}$	1.70
Ø	ANGLE OF SOFFICIENT, WHICH C _n C _y , C _z , C _y , C _z	5/:-
Θ	ANGLE OF YAW AT WHICH CA EQUALS ZERO	-12.9°

(B) ANGLE OF BANK COMPUTATION TABLE

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KIGUAE 14. - QUODERFARE TOIM CHAQACTERITICS WITH ASVAMETAIC DOWER AT LOM SOLEDS. FLIPS AND GEIR DOWN, TAKE-OFF DOWER ON RIGHT ENGINE. LEFT ENGINE DRODELLOR WINDMILLING. (A) MODEL CHARACTERISTICS DETERMINED FROM WIND-TUNNEL TESTS

0	87 NI 87 NI 87 NI	768	133R	515R	8% R	3 /SOFT	1 .	BY NI NOSER PEDAL
0	PEDAL FORCE	1/06			-	45 6	4 8	RIGHT 8
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(9)	ΔC_{h_p} of trim the set to trim with simplified frome E_{h_p}	800°+		·	-	a Sa	RUDDER PEDAL	
Ø	Chr FOR	-:014	020;	001.	081	3,148/sarr M ITEM 6 W TABLE		40
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0	FUDDER ANGLE	00	°01-	-20°	-250	(B)		RICHT &
							· · · · ·	

KN ANGLE OF SIDESLIP, B

F 8 Ó 9 140 °22- « " -25° " -100 5=00 0-0 A RUN 146, 0 RUN 14a, 0 RUN 14c P RUN 194 9 9 ġ -200

FIGURE 15.-RUDDERANGLE AND DEDAL FORCE NECESSARY TO HOLD ZERO SIDESLID WITH ASYMMETRIC DOWER AT LOW SOFED. FLADS AND GEAR UP, TAKE-OFF DOWER ON RIGHT ENGINE, LEFT ENGINE DROPELLOR WINDMILLING. TWIN-ENGINE (C) AIRPLANE STEADY SIDESLIP CHARACTERISTICS (A) MODEL CHARACTERISTICS DEFERMINED FROM WIND-TUNNEL TESTS

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LIGUAL IG. - RUDOLR ANGLE AND PLOAL FORCE NECESSARY TO HOLD 10° SIDESLID WITH ASYMMETRIC DOWER AT LOW SOLLD. FLADS AND GEAR DOWN, TAKE- OF E DOWER ONRIGHT ENGINE, LEFT ENGINE DROPELLOR WINDMILLING.